AD 747517

DEPARTMENT OF THE ARMY

U.S. ARMY FOREIGN SCIENCE AND TECHNOLOGY CENTER
220 SEVENTH STREET NE.
CHARLOTTESVILLE, VIRGINIA 22901

In Reply Refer to:
FSTC-HT-23- 899-72
DIA Task No. T70-23-01

Date: 3 July 1972

TRANSLATION

ENGLISH TITLE: Diagnosis of Motor Vehicle Engines Using Spectral Analysis of Spent Oil

FOREIGN TITLE: Diagnostika Avtomobil''nykh Dvigateley pri Pomoshchi Spektral'nogo Analiza Otrabotavshego Masla

AUTHOR: A. P. Boldin

LANGUAGE: Russian

SOURCE: Nadezhnost' i Diagnostika Agregatov i Sistem Avtomobiley [Reliability and Diagnosis of Motor Vehicle Units and Systems], Mowcow Institute of Motor Vehicles and Roads, pp 95-107.

TRANSLATOR: Albert L. Peabody
Leo Kanner Assocs.

REQUESTOR: AMXST-GE Mr. Warner

ABSTRACT: The method of spectral analysis of a liquid sample of spent oil using a rotating disk electrode is tested as a means for practical diagnosis of motor vehicle engines. Preliminary results indicate stability of concentration of wear products in spent oil, regardless of the mileage of the vehicles. Hidden defects in engines can be discovered in a timely manner on the basis of sharp increases in the concentration of corresponding elements in spent oil.

KEY WORDS: Motor Vehicle Maintenance
Diagnostic Methods
Motor Vehicle Engine
Spectrum Analysis
Lubricating Oil

This translation was accomplished from a xerox manuscript. The graphics were not reproducible. An attempt to obtain the original graphics yielded negative results. Thus, this document was published as is , in order to make it available on a timely basis.

12.

Tremendous funds are expended in the maintenance of motor vehicles in our country. Expenditures for maintenance and repair of motor vehicles amount to over 20% of the cost of transportation [7].

A large fraction of the labor and operation of expenditures consists of maintenance and repair of motor vehicle engines.

As a result of the significant variations in quality indicators of parts resulting from production and differences in operating conditions, wide fluctuations are observed in the service lives of motor vehicle engines. For example, the service life of YaAZ-204 engine to overhaul varies between 50 and 200 thousand kilometers, on the service life of new GAZ-21 engines varies between 70 and 205 thousand kilometers [7].

With these significant fluctuations in engine durabilities for identical engines, it is impossible to use norms of mileage to maintenance and overhaul, even if corrections are introduced to consider the operating conditions. We must note that these norms, established by observation of the operation of a large quantity of engines until complete failure, corresponds to the mileage at which only 10-15% of engines of the total number require service [6]. Using these norms, 85 to 90% of the engines are given clearly unnecessary maintenance or repair.

In connection with this, motor transport enterprises attempt to utilize the operating lives of engines more completely; after completion of the normal mileage, the possibility of further operation is decided on the basis of information provided by the driver on oil consumption, fuel consumption, power loss, smoking and knocking. This evaluation of engine reserve is quite subjective, since these characteristics depend on a large number of factors, the combination of which is difficult to consider (adjustment and condition of fuel supply system, ignition system, carburetors and manifolds, crankcase ventilation, etc).

At the present time, there are many methods of diagnosis of the technical condition of the cylinder-piston group of an engine. They include: measurement of compression, pressure, determination of gas volume penetrating to the

crankcase, pressure in the crankcase, vacuum in the intake manifold, measurement of compressed air leaks, etc. However, these methods do not provide the necessary reliability, since the results produced depend on a number of competing conditions (valve tightness, engine temperature, oil viscosity, battery charge, etc).

It is even more difficult to determine the condition of the joint between a crankshaft neck and bushing. Excessive wear of bearings is usually judged on the basis of the oil pressure in the lubrication system and characteristic noises in the engine. However, the noises become loud enough to hear only with clearances significantly exceeding the permissible clearances, and pressure depends not only on these clearances, but also on the operation of the oil pump, throughput capacity of the lubrication system, etc.

The subjectiveness of evaluation of the technical condition of an engine means that its maintenance or removal from operation is performed either too early, long before truely needed, or too late. In the former case, significant under usage of the operating life of the motor and its parts results, with early repair, preventing running in of joints and increasing the wear of parts. In the latter case, the rapidly increasing wear of the base part (cylinder liner or crankshaft neck) decreases the available operating life of the engine, and sometimes results in emergencies (seizing of a crankshaft neck, bronze bushing, etc.).

Figure 1 shows the results of the investigation of 75 GAZ-21 engines sent in for overhaul [3].

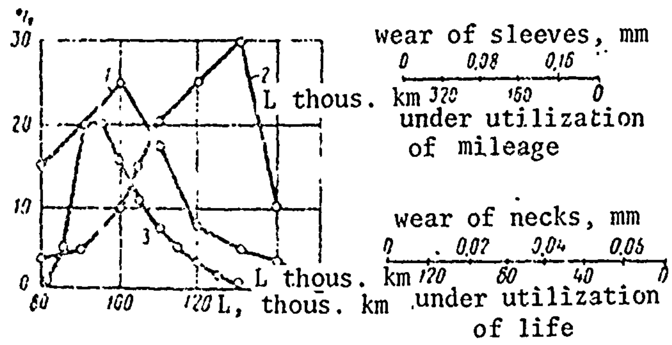

Figure 1. Distribution of Quantities:
1, wear of connecting rod necks of GAZ-21 engines sent in for overhaul; 2, mileages, 3, wear of sleeves.

The distribution of the wear of cylinder sleeves shows that about 80% of the GAZ-21 engines were sent in for overhaul too early. The under utilized reserve of these engines at the ordinary wear rate for a GAZ-21 engine of 0.5 μ per 1,000 km and the limiting permissible wear of sleeves of 0.20 mm averaged 200% for one engine, the possible increase in mileage was from 119 to 356 thousand km.

The distribution of connecting rod necks yields the same picture. With an average wear rate of 0.5 μ per 1,000 km and a maximum permissible wear of 0.07 mm, the under utilized engine life averaged 83%, the possible increase in mileage up to 220 thousand km.

A similar analysis of experimental data on 87 ZIL-130 engines [4], sent in for overhaul, showed that with an average life of 150 thousand km (spread from 60 to 280 thousand km), the under utilized life of these engines, based on the condition of cylinder sleeves, was 113%, based on the condition of connecting rod necks, 66%.

These examples confirm the tremendous importance of proper and timely determination of the technical condition of an engine without dissembly, i.e. of diagnosis.

Diagnosis of the technical condition of motor vehicles is a part of the process of motor vehicle maintenance and repair. It includes examination of mechanisms of the vehicle without dissembly in order to determine concealed defects, prevent sudden failures, determine the need for maintenance or repair, and predict the available life until the next maintenance operation.

In our opinion, one of the most promising methods of diagnosis of motor vehicle engines at the present time is determination of technical condition on the basis of the concentration of wear products in spent engine oil.

This method is based on the dependence of the wear rate of a friction couple on the condition of the friction contact [8]. On Figure 2, line A shows the wear of a friction part with the passage of time of operation. Sector I characterizes the running in of the friction couple; II characterizes the mode of stable wear; III characterizes the condition of progressing wear resulting from expenditure of the technical life of the couple. In this stage, the couple must be dissembled in order to restore its efficiency, since further operation will cause defects or breakage. The rate of wear is illustrated by curve B, which also has three characteristic sectors; I -- high wear due to running in of the couple; II -- stable wear, III -- high wear following utilization of the life of the couple.

Curve C shows the dependence on concentration of wear products in the spent engine oil on the operating time of the engine. When the engine operates at a constant load and speed mode, the content of wear products in the spent oil falls at a certain constant level due to the dynamic equilibrium between arrival of wear products in the oil and removal by the oil filtration system and oil loss.

Analytic solution of the conditions of equilibrium for the case when an engine operates at a constant mode with a constant volume of oil in the crankcase yields the following dependence for the concentration of wear products in the spent oil [10]

$$[illegible]\, e^{-\frac{[illegible]}{Q_0}t} + \frac{v}{q_n + q_y}\left(1 - e^{-\frac{q_n + q_y}{Q_0}t}\right). \qquad (1)$$

where k_0 is the initial concentration of impurities in the oil, kg/kg;

Q_0 is the initial quantity of oil in the engine lubrication system, kg;

g is the intensity of arrival of impurities in the oil, kg/hr;

τ is the duration of operation of the engine since oil change, hr;

q_u is the intensity of oil loss, kg/hr;

$q_n = q_{m\cdot o}\,\eta_{m\cdot o}$ is the useful intensity of delivery of oil to the oil filter (here $q_{m\cdot o}$ is the intensity of passage of oil through the oil filter, kg/hr; $\eta_{m\cdot o}$ is the efficiency of purification with one time passage of oil through the oil filter.

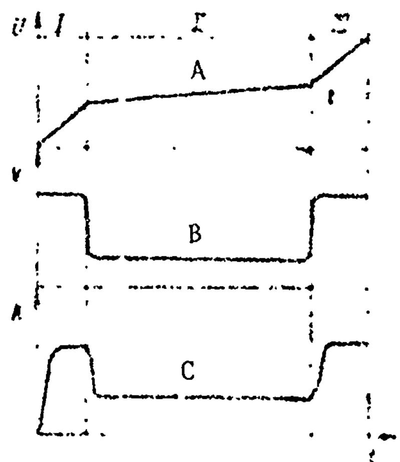

Figure 2. Typical Classical (Idealized) Dependences of Wear of Friction Couple of Motor Vehicle Engine Mechanisms.

As we can see from equation (1), with sufficiently high operating time of the engine, the concentration of wear products in the oil is independent of the initial concentration, and is determined by the expression

$$k = \frac{g}{q_n + q_y}. \qquad (2)$$

The equilibrium is established more rapidly, the less the volume of oil in the crankcase, the higher the values of oil loss and degree of oil purification. As experiments have shown, the concentration stabilizes in truck engines after approximately 2 hours [1].

Thus, an increase in the concentration of wear products in the oil will indicate an increase in the intensity of wear of the engine, which might be caused by entry of a large quantity of dust into the oil due to defects in the air cleaner, worsening of the physical or chemical properties of the oil or by expenditure of the operating life of a friction couple.

Since a motor vehicle engine operates at various, randomly changing loads and speeds, the concentration of wear products in the oil also changes randomly over certain intervals. Its quantity will depend on the individual properties of the engine, the quality of driving, servicing, etc., and for each engine will have a certain average value, reflecting the actual wear rate.

The basic engine parts consist of characteristic metals and alloys, so that the presence of various elements in the oil and their per cent content allow the rate of wear of the corresponding parts and couples to be determined. Thus, the concentration of iron determines the wear of cylinders and crankshaft necks. The content of nickel indicates the wear of the upper portion of the cylinder (if the engine has a small sleeve of nickel-alloy cast iron). The presence of lead in the oil indicates wear of the crankshaft bearing, since alloy SOS-6-6 consists of 88% lead. Chromium in the oil is an indication of wear of the upper compression rings, the condition of which basically limits the efficiency of the cylinder-piston group. Aluminum indicates wear of the pistons, while copper indicates wear of the bronze wrist pin bushings. Parts in the manifold have slight wear and long durability [2], so that careful testing of their wear produces no significant economic effect.

At the present time, there are several methods allowing determination of the presence of iron, chromium, aluminum, lead, copper, nickel and other elements in the oil.

The basic difficulty involved in the determination results from the fact that these elements are present in spent oil in very slight quantities, on the order of 0.0001-0.01%. Measurement of these concentrations by chemical methods is very difficult and time consuming.

The method of neutron activation of the oil and polarographic analysis, although it allows separate determination of the concentration of all these elements in the oil, requires complex preparation of a specimen. In the first case, an oil specimen is bombarded with a stream of neutrons, so that the wear products become radioactive, and the radiation energy is used to determine the concentration of the necessary elements. In the second case, the oil is preliminarily ashed, the residue is dissolved in acids, and the solution is analyzed on a polarograph. Due to their cumbersomeness, these methods have not been practically used to estimate the wear of large numbers of engines and are used primarily for scientific investigations.

At the present time, spectral methods of determining wear products in spent oil are becoming evermore widespread. These methods can be divided into 2 groups: methods in which the oil is preliminarily ashed and the content of the elements being analyzed is determined in the ash, and methods of direct analysis of a liquid oil specimen.

Among the methods of the first group, the following is the most widely used [5]. A charge of 5-10 g oil is ashed by burning in a crucible, then the residue is heated in a muffle furnace at 600-800°C to complete removal of the black. The ash produced is mixed with 3 or more weight parts of powdered graphite and lithium fluoride, the mixture is carefully ground in an agate mortar and the recess in a specially designed electrode is filled with this

mixture (Figure 3a). An electrical current arc burns between the electrodes. The recess in the electrode burns together with the powdered specimen. The elements present in the specimen are excited in the plasma and their radiation is recorded by a spectral apparatus. Standards for quantitative analysis are prepared of salts or oxides of the elements being determined by dilution with graphite powder and lithium fluoride. The method produces high sensitivity of determination of all elements, but is rather time consuming.

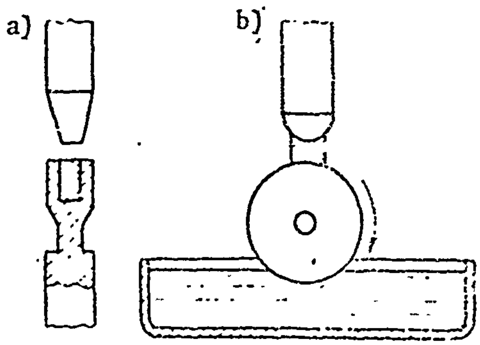

Figure 3. Diagrams of Spectral Analysis of Oils:
a, method of ashing of a specimen; b, method of burning of a liquid specimen using a rotating disk electrode.

Spectral analysis of a liquid oil specimen can be most easily performed using a rotating disk electrode (Figure 3b). Rotating at 4-6 rpm, the disk electrode is moistened and feeds an even film of oil into the arc discharge, the radiation of which is recorded by the spectral apparatus. With properly selected modes, this method provides good sensitivity and accuracy of analysis.

A method of spectral analysis of spent oil using a rotating disk electrode has been developed in the Department of Operation of Motor Vehicle Transport Equipment of the Moscow Motor Vehicle and Road Institute, which, in contrast to the TsNII MPS method [9], has the following specific features:

it is designed for analysis of less viscous motor vehicle oils (6-10 cst at 100°C);

the standards for quantitative analysis are prepared using an aqueous solution of salts of the elements being analyzed, not by contamination of pure oil with oxides.

Analysis of the oil is performed on a Type ISP-28 spectrograph, the standard supporter of which has been specially modified.

Six grams of oil are placed in a bath measuring 60 × 10 × 10 mm. A carbon disk electrode 13.5 mm in diameter and 3 mm thick rotates at 5 rpm. The arc used is fed by 220 v ac, the analytic gap is 1.5 mm, the slit of the spectrograph is 0.015 mm, exposure 90 sec, preliminary burning 24 sec, spectral plates (Type I), sensitivity 1 unit (GOST 2817-50).

For oils with a viscosity of 6 cst at 100°C, a current of 5.5 a is used, for oils with a viscosity of 10 cst -- 6.5 a.

The sensitivity of determination of the quantity of iron, lead and silicon is 0.00001%, for chromium, copper and aluminum -- 0.00001%, allowing spent oil to be analyzed with any technical condition of the engine. The maximum deviation of the results of analysis with 10 times repetition does not exceed 30%. This accuracy is satisfactory for objective evaluation of the condition of an engine on the basis of a single analysis of a specimen.

Analysis of liquid specimens of 20 samples of oil (one photographic plate) for 6 elements requires 12 man hours, and the results of analysis can be produced 48 hours following taking of the specimen from the engine. When spectral diagnosis is introduced to the practice of operations at large motor transport enterprises, further increases in productivity of analysis are possible by using spectral apparatus with photoelectric recording of spectra. Using this technology, one analysis requires 4 to 5 minutes and its results are immediately available.

The author has performed preliminary studies of the possibility of using spectral analysis for the diagnosis of motor vehicle engines under the conditions of a large motor transport enterprise. The purposes of the investigations were:

to study the nature of the change in concentration of wear products in spent oil as a function of service life of engines, based on vehicle mileage;

to determine the spread of concentrations and establish approximate maximum permissible norms for the content of wear products in oil.

This problem was solved using statistical processing of the results of analysis of oils taken from the crankcases of 130 ZIL-120 engines. The oil specimens were taken in July of 1966 at the third bus pool in Moscow using buses which had completed maintenance cycle TO-1. The random sample included new and overhauled engines with various mileages.

Oil specimens were taken in warm but nonoperating engines 10 minutes after they were stopped through the oil dipstick hole. At the moment of sampling, the engines had run for an average of 1,800 km since the last oil change. The specimens were taking using a syringe with a capacity of 150 cm^3. The level of sampling corresponded to half the distance between the upper and lower marks on the dipstick. The oil specimen was placed in a clean bottle (250 cm^3 volume), which was filled approximately halfway for convenience of shaking before analysis.

The oil specimens were analyzed according to the method described above. The content of lead, iron, chromium, copper, aluminum and silicon was determined. Two groups of engines were differentiated: new and overhaul. The nature of the change in concentration of elements as a function of engine service life or bus mileage was determined for each group using the least squares method.

Initially, the dependence of iron content in the oil on silicon content was determined, characterizing the influence of the quality of operation of the air

cleaner on the intensity of wear of the engine. Figure 4a shows the sharp increase in iron content in the oil with increasing silicon.

Figure 4b shows the statistical distribution of silicon content in specimens of oil from the crankcases of 130 ZIL-120 engines. As we go over from the rapid drop in distribution density to its approximately constant value, we note the upper limiting permissible content of silicon in the spent oil, which was $10 \cdot 10^{-4}\%$. We found that approximately 23% of the engines were operating with poor quality air cleaners, due to poor quality maintenance or poor technical condition of the air cleaners. The oil specimens from these engines were eliminated from our further processing.

We must note that the limiting permissible content of elements in the oil must have some technical-economic basis.

Figure 5a shows the nature of the change in the content of iron in the oil as a function of service life of engines, based on bus mileage. As we can see from the Figure, for a normally operating engine the concentration changes only slightly with increasing mileage. The concentration of iron in the oil of overhauled engines is approximately twice that of new engines. This indicates that the wear rate of new engines is approximately half that of overhauled engines.

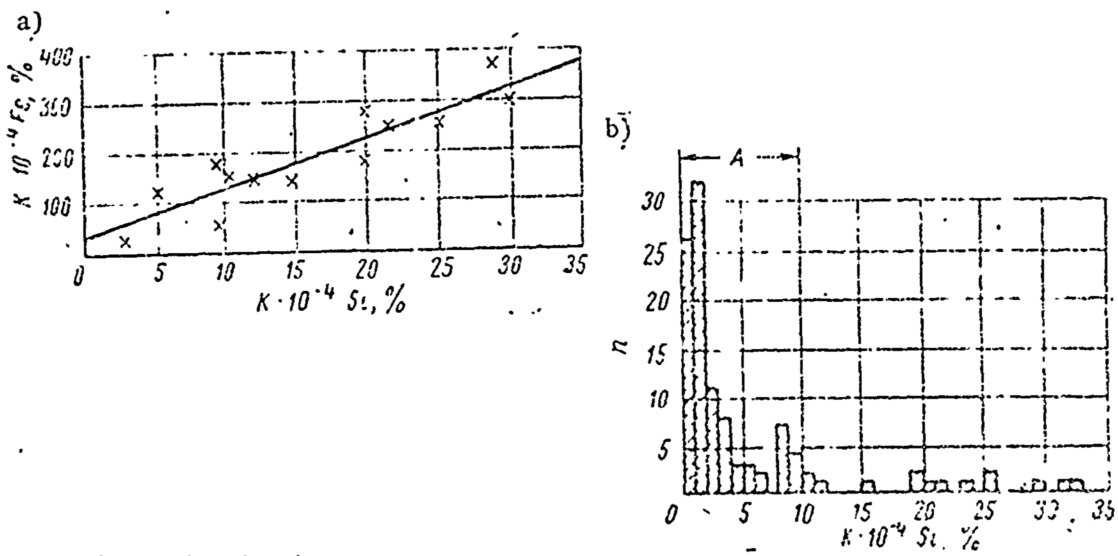

Figure 4. Graphs:
a, content of iron in spent oil of engine as a function of silicon content; b, statistical distribution of content of silicon in spent oil of engine; A, limiting permissible silicon concentration.

Similar processing of the results of studies for the remaining elements showed that the content of lead, copper and aluminum in the spent oil of engines remains practically constant with increasing mileage. The content of lead and aluminum in the oil of overhauled engines is approximately twice that of new engines. The content of copper is approximately the same for both groups of engines. Due to the extremely low content of chromium, it was observed only that 40% of the specimens

observed only in 40% of the specimens only for those engines showing increase wear of the upper compression rings due to the high silicon content or great age of the rings.

The significant spread of concentration of elements in the oil observed for correctly operating engines indicates the individuality of types of wear of each individual engine. However, this spread, with normal technical condition, does not extend beyond the limiting permissible indicators. Figure 5b shows the statistical distribution of one of the most important wear products in spent oil -- iron. the limiting permissible content of iron was found on the basis of the density of this distribution. For overhauled engines, it was $60 \cdot 10^{-4}$%, for new engines half this great, i.e. $30 \cdot 10^{-4}$%. About 43% of the engines tested had increased iron content in the oil and require that action be taken to reduce the wear rate (servicing of the air cleaner or oil filter, replacement of the piston-connecting rod group). Since the concentration of iron in the oil is practically independent of the service life of the engines, this distribution and the limiting norms will be comparable for any interval of engine operation.

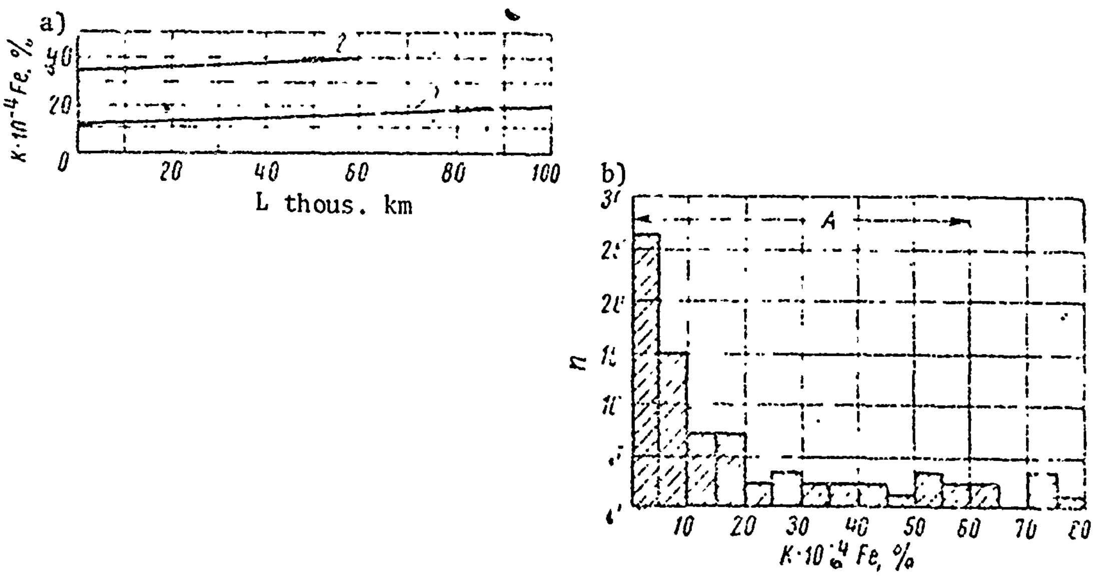

Figure 5. Graphs:
a, change in iron content in spent oil as a function of service life of engines (vehicle mileage); b, statistical distribution of iron content in spent oil of engines; A, limiting permissible concentration of iron in oil; 1, new engines; 2, overhauled engines.

Analysis of the distribution of lead in the oil shows that the spread of concentrations lies between $1 \cdot 10^{-4}$% and $90 \cdot 10^{-4}$%. An upper limiting permissible value of $8 \cdot 10^{-4}$% was selected for overhauled engines, with a limit of $4 \cdot 10^{-4}$% for new engines.

The maximum content of chromium was $11 \cdot 10^{-4}$%, the upper limit 0.1--$1 \cdot 10^{-4}$%.

The content of aluminum varied from $0.2 \cdot 10^{-4}$% to $300 \cdot 10^{-4}$%. The upper limiting permissible concentration was $4 \cdot 10^{-4}$% for new engines and 8 10^{-} % for overhauled engines.

The content of copper fell within limits from $0.2 \cdot 10^{-4}$% to $200 \cdot 10^{-4}$%. The limiting permissible concentration was $7 \cdot 10^{-4}$%.

Further studies designed to refine the indicators of limiting permissible concentrations and establish a proper interval for diagnosis are being performed by systematic observation of an experimental group of vehicles.

Conclusions

1. The good accuracy and high productivity of spectral analysis of a liquid spent oil specimen using a rotating disk electrode indicates the possibility of practical application of this method for the diagnosis of motor vehicle engines.

2. Preliminary results indicate stability of the concentration of wear products in spent oil, regardless of vehicle mileage.

3. Hidden engine defects can be detected early by a sharp increase in the concentration of the corresponding elements in the oil.

4. Statistical processing of massive analyses of spent oil specimens from engines allows approximate establishment of the upper limiting permissible norms for the content of the main elements in the oil, exceeding which indicates a specific defect in the engine and necessity of its elimination. These norms require further refinement by consideration of economic factors and comparison of the data of spectral analysis with micrometer measurement results.

5. The results of the investigation indicate the expediency of using spectral analysis of spent oil for diagnosis of motor vehicle (carburetor) engines.

BIBLIOGRAPHY

1. Balkushkonis, V. I., "Study of the Filtering Capacities of an Oil Filter," Dissertation.

2. Gurvich, I. B., Iznos Avtomobil'nykh Dvigateley [The Wear of Motor Vehicle Engines], MASHGIZ Press, 1961.

3. Donskoy, D. I., "Study of Wear and Deformation of Parts in "Volga" Automobile Engines," Avtomobil'naya Promyshlennost', No 3, 1964.

4. Dyumin, I. Ye., Podshchekoldin, M. I., Preysman, V. I., "Study of the Durability of the ZIL-1[illegible]0 Engine and Wear of its Most Important Parts," Avtomobil'naya Promyshlennost', No 2, 1966.

5. Il'ina, Ye. V., "Determination of Impurities in Oils by Ashing of Specimens," Primeneniye Spektral'nogo Analiza Masel dlya Pov'sheniya Nadezhnosti i Dolgovechnosti Mashin i Mekhanizmov [Application of Spectral Analysis of

Oils to Increase Reliability and Durability of Machines and Mechanisms -- Materials of a Seminar], Moscow, MDNTP Press, 1965.

6. Kuznetsov, Ye. S., "Methods of Determining Periodicity of Maintenance and Expediency of Performance of Forced Repair," Avtomobil'naya Promyshlennost', No 6, 1965.

7. Koregyan, S. K., "National Economic Significance of Methods of Evaluation of Reliability and Durability of Internal Combustion Engines," Primeneniye Spektral'nogo Analiza Masel dlya Pov'sheniya Nadezhnosti i Dolgovechnosti Mashin i Mekhanizmov [Application of Spectral Analysis of Oils to Increase Reliability and Durability of Machines and Mechanisms -- Materials of a Seminar], Moscow, MDNTP Press, 1965.

8. Pakhomov, E. A., Chankin, V. V., "Economic Expediency of Determining the Condition of Heat Engines without Dissembly by Spectral Analysis of Oils," Primeneniye Spektral'nogo Analiza Masel dlya Pov'sheniya Nadezhnosti i Dolgovechnosti Mashin i Mekhanizmov [Application of Spectral Analysis of of Oils to Increase Reliability and Durability of Machines and Mechanisms -- Materials of a Seminar], Moscow, MDKTG Press, 1965.

9. Chankin, V. V., "Express Photoelectric Method of Analysis of Diesel Oils," Primeneniye Spektral'nogo Analiza Masel dlya Pov'sheniya Nadezhnosti i Dolgovechnosti Mashin i Mekhanizmov [Application of Spectral Analysis of Oils to Increase Reliability and Durability of Machines and Mechanisms -- Materials of a Seminar], Moscow, MDNTP Press, 1965.

10. Chankin, V. V., Pakhomov, E. A., "Dynamics of Measurement of Concentration of Impurities in Crankcase Oil," Vestnik Vsesoyuznogo Nauchno-Issledobatel'skogo Instituta Zheleznodorozhnogo Transporta, No 6, 1964.